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13. ABSTRACT (Maximum 200 words)

We have made significant progress in our understanding of ultrafast electronic processes in semiconductor nanostructures by developing a detailed theory for electron-phonon many body interaction processes in GaAs quantum wires of 10-100 nanometers cross-sectional dimensions. Specifically, we have taken into account plasmon-plasmon and quasiparticle-phonon coupling effects in calculating femtosecond hot electron relaxation phenomena, showing that many-body coupling could lead to substantial enhancement in the energy loss rates of ultrafast electrons confined in semiconductor quantum wire nanostructures. We have also developed a quantitative theory, agreeing very well with experimental results, for electronic tunneling in GaAs-AlGaAs double quantum well structures taking Coulomb interaction induced many-body effects into account. We published 37 papers and produced 2 Ph.d.s under this project.

14. SUBJECT TERMS
Electron-phonon interaction; GaAs quantum wires; plasmon-phonon coupling; hot electron energy loss; Coulomb scattering

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FINAL REPORT ON US-ARO GRANT DAAH 04-93-G-0005

A. Statement of the Problem Studied

In our project, we have studied and finished the theoretical problems we originally proposed in our grant proposal. The specific problem we studied pertains to ultrafast (picosecond to femtosecond) electronic phenomena in low dimensional semiconductor nanostructures (e.g. quantum wells, quantum wires, quantum dots, multilayer superlattices, modulation doped heterojunction transistors). The theory we develop should apply to most compound semiconductor materials, but our specific numerical results are mostly for the GaAs-Al GaAs structures because of their technological relevance (and also because much experimental data are available for GaAs based nanostructures). We compare our theoretical results with the available experimental results, and find very good agreement. In summary, we accomplished all aspects of our originally proposed project.

B. Summary of the Most Important Results

(1). Hot Carrier Relaxation in Nanostructures

We have developed a complete theory, taking full account of many-body effects, for hot electron relaxation in quantum wire structures. The theory includes plasmon-phonon and quasiparticle-phonon couplings as well as optical phonon bottleneck effect (the so-called "hot phonon" effect). We consider both Fröhlich coupling to LO-phonons and deformation potential coupling to acoustic phonons. The theory is in very good agreement with the available experimental results.

(2). Hot Phonon Lifetime

We have studied in quantitative details the effect of hot phonon lifetime on hot electron relaxation rate in doped nanostructure materials.

(3). Femtosecond Dynamics

We have developed a detailed theory for electron-electron and electron-phonon interaction effects on carriers confined in quantum well and quantum wire structures at the femtosecond time scale.

(4). Single Electron Tunneling

We have developed a detailed theory for single electron tunneling in double quantum well structures, which takes into account electron-electron, electron-phonon, and electron-impurity interaction effects.

(5). Optical Properties of Quantum Dots and Wires

We have developed a theory for optical properties of semiconductor nanostructures by calculating the collective plasmon spectra and band gap renormalization.

(6). Device Simulation

We have done a device simulation calculation for modulation doped heterojunctions by taking into account the correlation among the remote dopant sites.

C. List of Publications

1. Self-Consistent Electronic Structure of Parabolic Semiconductor Quantum Wells Inhomogeneous Effective Mass and Magnetic Field Effects (M. P. Stopa and S. Das Sarma), Phys. Rev. B 47, 2122 (1993).

2. Electronic Properties of Quasi-One Dimensional Semiconductor Nanostructures: Plasmons and Exchange-Correlation Effects (S. Das Sarma and B.Y.K. Hu), Australian J. of Phys. 46, 359 (1993). Invited Review.

3. Low Temperature Thermal Relaxation of Electrons in One Dimensional Nanostructures (S. Das Sarma and V. B. Campos), Phys. Rev. B 47, 3728 (1993).

4. Many-Body Coupling Between Quasiparticle and Collective Excitations in Semiconductor Quantum Wells (S. Das Sarma and I. K. Marmorkos), Phys. Rev. B. 47, 16343 (1993).

5. Collective Excitations of Parabolically Confined Low Dimensional Electron Systems in Semiconductor Nanostructures (S. Das Sarma), p. 19 in the book "Topics in Condensed Matter Physics" (Nova, New York, 1994). Invited Review.

6. Elementary Excitations in a Finite Fractional Quantum Hall Droplet (X. C. Xie, S. Das Sarma, and S. He), Phys. Rev. B 47, 15942 (1993).

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10. Electron-Phonon Interaction, Kohn Anomalies, and Peierls Transition in Semiconductor Quantum Wires (J. R. Senna and S. Das Sarma), Phys. Rev. B 48, 4552 (1993).

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14. Electron-Hole Plasma Driven Phonon Renormalization in Highly Photoexcited GaAs (S. Das Sarma and J.R. Senna), Phys. Rev. B 49, 2443 (1994).

15. LO-Phonon Emission by Hot Electrons in One-Dimensional Semiconductor Quantum Wires (S. Das Sarma and V.B. Campos), Phys. Rev. B 49, 1867 (1994).

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17. Collective Excitations in Asymmetric Parabolic Quantum Wells (P. I. Tamborenea and S. Das Sarma), Solid State Communications 89, 1009 (1994).

18. Collective Excitations in Imperfect Parabolic Quantum Wells with In-Plane Magnetic Fields (P. I. Tamborenea and S. Das Sarma), Phys. Rev. B 49, 16593 (1994).

19. Relaxation of Hot Electrons in One-Dimensional Nanostructures (V. B. Campos and S. Das Sarma), Brazilian J. of Phys. 24, 307 (1994). Invited Review.

20. On Giant Many-Body Enhancement of Low Temperature Thermal Electron-Acoustic Phonon Coupling in Semiconductor Quantum Wires: Das Sarma and Senna Reply (S. Das Sarma and J. R. Senna), Phys. Rev. Lett. 72, 2813 (1994).

21. Screening and Many-Body Effects in Low-Dimensional Electron Systems (S. Das Sarma), p. 339 in the book "Quantum Transport in Ultrasmall Devices" (Plenum, New York, 1995). Invited Review.

22. Dynamic Magnetoconductance Fluctuations and Oscillations in Mesoscopic Wires and Rings (D. Z. Liu, B.Y. K. Hu, C. A. Stafford, and S. Das Sarma), Phys. Rev. B (Rapid Commun.) 50, 5799 (1994).

23. Vertex-Correction-Driven Intersubband-Spin-Density Excitonic Instability in Double Quantum Well Structures (S. Das Sarma and P. I. Tamborenea), Phys. Rev. Lett. 73, 1971 (1994).

24. Collective Excitations of a Two-Component One-Dimensional Quantum Plasma Confined in Semiconductor Quantum Wires (E. H. Hwang and S. Das Sarma), Phys. Rev. B 50, 17267 (1994).

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31. Dynamical Response of a One Dimensional Quantum Wire Electron System (S. Das Sarma and E.H. Hwang), Phys. Rev. B 54, 1936 (1996).

32. Energy Relaxation of an Excited Electron Gas in Quantum Wires: Many-Body Electron LO-phonon Coupling (Lian Zheng and S. Das Sarma), Phys. Rev. B 54, 2751 (1996).

33. Quasiparticle Properties of a Coupled Quantum Wire Electron-Phonon System (E.H. Hwang,Ben Yu-Kuang Hu, and S. Das Sarma), Phys. Rev. B 54, 4996 (1996).

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D. Personnel Supported by the Grant

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Report of Inventions

None